Quantitative risk assessment of human salmonellosis through consumption of pork in Belgium: a modular risk model

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Abstract

As *Salmonella* Typhimurium (STM) is the major source of human salmonellosis in Belgium, a quantitative microbial risk assessment (QMRA) to evaluate the health risks associated with the consumption of minced pork meat contaminated with STM in Belgium was initiated. The QMRA model describes the chain from farm-to-fork, dividing the exposure pathway into several modules (1) primary production, (2) transport & holding, (3) slaughter & processing, (4) distribution & storage and (5) consumer. Both fresh and frozen minced meat products prepared at home are considered and human illness is estimated for both inadequately cooking and cross-contamination during preparation. Data relevant to the Belgian situation was incorporated into the model where available, international and literature data was used otherwise. First baseline results of the model are presented and the impact of some scenarios was investigated. These first results show that there seems to be more potential in reducing the STM load on the carcasses, rather then reducing the prevalence.

Introduction

In 2006, *Salmonella* was the second most common cause of gastrointestinal disease in Belgium and was isolated from 3670 human cases of gastroenteritis. *Salmonella* Typhimurium (STM) contributed to 49.4% of these human cases (personal communication with Nadine Botteldoorn). As STM is the most common serovar isolated from pigs (Botteldoorn *et al.*, 2003), it is clear that the consumption of pig meat is an important risk factor. Therefore, a quantitative microbial risk assessment (QMRA) was developed to evaluate the health risks associated with the consumption of minced pork meat contaminated with STM in Belgium. The main objectives of this QMRA are threefold: (1) the development of a modular risk model, (2) the investigation of the quality of information and assumptions of the risk model and (3) the optimization of the risk model and the implementation of mathematical and statistical refinements. There are several QMRA's estimating the risk to human health from STM originating from pigs meat (Hill *et al.*, 2003; Ranta *et al.*, 2004; van der Gaag, 2004; Alban & Stärk, 2005) using different approaches.

The approach followed in this project is based on the Hill-model. Data relevant to the Belgian situation was incorporated into the model where available, international and literature data was used otherwise. Some adaptations to the model were made in among others the partitioning, cross-contamination and dose response models. To take the imperfect nature of the available data as much as possible into account, a methodology for assessing the quality of data and information sources (based on a multi criterion pedigree matrix) was developed in parallel.

The model

The model is based on the model of Hill (2003) (Figure 1). The current model is only applicable to minced pig meat.

Several adaptation were made to the original model. Some are highlighted in this paper.
(1) Primary production. The mechanistic farm model in the original model was replaced by a seroprevalence estimation based on data from the national *Salmonella* surveillance program. This estimation was done by using generalised estimating equations, taking into account the sensitivity and specificity of the test used. The data differentiates between the weight category of the pigs and the time of sampling. The farm model is used to calculate the ratio between infected and carrier animals.
(2) Module transport. During the transport & holding phase there is a possible state transition of animals. Since the average time in this module is very similar to the current practice in the UK, the original model seems to be applicable for Belgium.
(3) Slaughter & processing. The slaughter process has not been modified, apart from the carcass weight which has significantly increased in recent years.

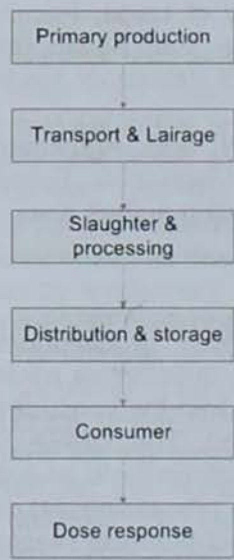

Figure 1: Schematic overview of the modular QRMA

Data obtained by a survey of 11 Belgian pig meat processors has been incorporated in the processing model. The partitioning of the meat mix is completely redone according to the concept introduced by Nauta *et al.* (2001): $\text{BetaBin}(N_{mix}, b, b(n\text{-}1)$ with N_{mix} the number of *Salmonella* in the meat mix, b a cluster parameter (b=0.22 (Nauta *et al.*, 2001)) and n the number of units.
(4) Distribution & storage. For this module, data obtained by surveys among four Belgian retailers (comprising > 50% of the market) and 3000 consumers (Devriese *et al.*, 2006) concerning the time/temperature of storage were used.
(5) Preparation & consumption. Consumer data was used to make the model applicable for the Belgian condition. Cross contamination in the kitchen was modeled analogously to the WHO model of *Salmonella* Enteritidis in eggs (World Health Organization, 2003), adapted with the concepts described by Nauta *et al.* (2005) in their risk assessment of *Campylobacter* in broilers (CARMA).
(6) Dose-response. Based on the *Salmonella* outbreak data described in World Health Organization (2003), a novel dose response model was developed based on fractional

polynomials. This model differentiates between a normal and a sensitive population, and between the different *Salmonella* serovars.
(7) Data. The quality of data to be used in a QMRA is very diverse, but has a large impact on model results. One of the goals of the project was to develop a methodology to allow for an as objective as possible quantification of data quality. This methodolgy is based on pedigree scoring (Boone *et al.*, 2007) and was applied to identify these data sources that are most likely to yield the most reliable and useful data.

Session 1

Results

Preliminary results of the risk model are summarized in Table 1, where the risk of salmonellosis per serving of minced pork meat is shown. This risk is in general so small that a large number of iterations is needed to obtain a reasonably reliable estimation of the output distribution. The numbers presented here are the result of one million iterations. The average value of the risk was calculated as 2.08×10^{-4} (sd. 6.16×10^{-3}) and the corresponding number of yearly cases, based on the estimated number of servings, is then 67076 (sd. 17123). The reported number of cases due to STM is 1813 in 2006. Taking into account that there is an estimated underreporting of about 90%, the model output is in fact quite realistic. The risk is mainly determined by cross contamination 2.06×10^{-4} (sd. 6.15×10^{-3}) and only to a small extent to undercooking 2.83×10^{-6} (sd. 5.85×10^{-4}).

Table 1: The effect of mitigation strategies on the risk of illness from minced pork meat

	Scenario	Mean	Standard deviation
Baseline*		2.02×10^{-4}	5.74×10^{-3}
Seroprevalence at the farm	20% reduction	1.69×10^{-4}	5.01×10^{-3}
	40% reduction	1.60×10^{-4}	5.04×10^{-3}
	60% reduction	1.59×10^{-4}	5.25×10^{-3}
	80% reduction	5.68×10^{-5}	2.68×10^{-3}
Salmonella load on carcass after stunning and killing	1 log reduction	1.52×10^{-5}	1.79×10^{-3}
	2 log reduction	3.29×10^{-7}	1.04×10^{-4}
	3 log reduction	0	0
Salmonella load on carcass after meat inspection	0.5 log reduction	6.36×10^{-5}	2.80×10^{-3}
	1 log reduction	2.1×10^{-5}	1.79×10^{-3}
	2 log reduction	1.69×10^{-7}	4.41×10^{-5}
Prevalence of *Salmonella* - carcass contamination after meat inspection	10% reduction	2.02×10^{-4}	5.80×10^{-3}
	20% reduction	2.08×10^{-4}	5.85×10^{-3}
	30% reduction	2.13×10^{-4}	5.97×10^{-3}
Probability of ineffective cleaning during jointing (30% baseline)	20%	1.74×10^{-4}	5.35×10^{-3}
	10%	2.19×10^{-4}	6.36×10^{-3}
	0%	1.89×10^{-4}	5.69×10^{-3}

Percentage of minced meat destined for the frozen market (26% baseline)	100%	0	0
	75%	6.96×10^{-5}	3.51×10^{-3}
	50%	1.66×10^{-4}	5.19×10^{-3}
	0%	2.74×10^{-4}	6.78×10^{-3}
Storage temperature of fresh minced meat at home	-1°C reduction	1.57×10^{-4}	5.57×10^{-3}
	-2°C reduction	1.02×10^{-4}	4.27×10^{-3}
	-3°C reduction	8.58×10^{-5}	4.15×10^{-3}
	-4°C reduction	5.90×10^{-5}	3.24×10^{-3}
	-5°C reduction	4.69×10^{-5}	3.23×10^{-3}
	-6°C reduction	4.82×10^{-5}	2.83×10^{-3}
Percentage who defrost minced meat product at room temperature (48.8% baseline)	40%	2.22×10^{-4}	5.89×10^{-3}
	30%	2.09×10^{-4}	6.05×10^{-3}
	20%	1.91×10^{-4}	5.81×10^{-3}
Percentage of change in behaviour during food preparation (cross contamination)	3% reduction	1.96×10^{-4}	3.55×10^{-3}
	7% reduction	2.05×10^{-4}	5.81×10^{-3}
	25% reduction	1.94×10^{-4}	5.58×10^{-3}
	50% reduction	1.90×10^{-4}	5.54×10^{-3}

Discussion

The model in its current state produces already realistic results and allows testing mitigation strategies. The results of these indicate that there are certain strategies that are possibly more worthwhile to pursue than others. Reducing the STM-load seems to be much more efficient than trying to reduce the overall prevalence. This raises the question whether the monitoring program in place today, based solely on *Salmonella* seroprevalence of pigs and *Salmonella* prevalence of pig carcasses, pork meat and minced pork meat, is the most effective way of following up the problem. In this context, it has to be remarked here that the modeling of the slaughter process appears to be one of the weakest links of the model: it is based on only two data sources (Berends *et al.*, 1998; Davies *et al.*, 1999). Since the STM concentration has such a large impact there is a definite need to collect more quantitative data in the slaughtering plants.

Another important factor is the percentage of minced meat destined for the frozen market. Freezing has a profound positive impact on the risk and could thus be considered as a valid mitigation strategy. However, there are economic and consumer consequences to be considered as well, which falls outside the scope of this paper.

Storage conditions (time and temperature) in retail and especially households prove to be important factors, and could be improved by stringent controls and conscience raising campaigns. There seems to be less to gain by trying to improve food handling in the kitchen. The cost to reach consumers is large whilst only a small fraction (0-7%) of the consumers is willing to change their behaviour. Moreover the risk is not reduced significantly.

Session 1

Conclusion

The current QMRA model for STM in pigs is already usable and allows assessing the most efficient intervention strategies. There is still room for improvement though, and especially the description of the slaughtering process requires more data.

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